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Multispectral Image Maps From Landsat Thematic Mapper Data

Robert S. Rand
Donald A. Davis
John E. Anderson

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U.S. Army Corps of Engineers
Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060-5546

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Robert S. Rand John E. Anderson
Donald A. Davis

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This report describes a capability to produce prototype 1:50,000 scale multispectral image maps using Landsat TM data. These image maps are in the standard UTM projection, contain imbedded 1,000 meter grid lines with labeled UTM coordinates, and can easily be used in conjunction with conventional military maps of the same scale. Annotation that gives the title of the standard DMA map of the area, the Landsat TM band combinations, as well as a bar scale and compass were also imbedded into the product.

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PREFACE

The Image Map Border Project was tasked by the Army's Office of Deputy Chief of Staff Intelligence (DAMI-ISP), with Dan Smith as Project Director. Three Army organizations were involved: the U.S. Army Engineer Topographic Laboratories (ETL), Fort Belvoir, VA; the U.S. Army 30th Engineer Battalion (Topographic), Fort Belvoir, VA; and the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The Border Project team at ETL consisted of Joseph Watts as Project Manager (CEETL-GSL); Robert Rand, Donald Davis, and John Gundy as the Image Map production team (CEETL-SPL); John Anderson as the producer of the Image Portfolio (CEETL-TDL); Bob Satterwhite as remote sensing consultant (CEETL-RI); Alan Geralnick as consultant for potential Geographic Information System applications (CEETL-TDL); and Ann Benn as terrain analysis consultant (CEETL-TAC). The hardcopy support was provided by Ron Gillmore (Geotechnical Lab) and Mark Graves (Environment Lab) at WES. Hardcopy support was also provided by Geoffrey Strayer (RTS-3D) at DIA. The effort was conducted during the period of October 1988 to June 1989.

Col. David F. Maune, EN, was Commander and Director, and Mr. Walter E. Boge was Technical Director of the U.S. Army Engineer Topographic Laboratories during the project.

1.0 INTRODUCTION

1.1 Purpose

The objective of this effort was to demonstrate an Army capability for producing prototype image maps derived from Landsat Thematic Mapper (TM) imagery in both digital and hardcopy form. Under this demonstration ETL would generate the digital version of the image maps at its own computer facility, and send the digital data to an appropriate hardcopy production facility. Also, ETL would document the essential techniques used for the digital production from Landsat TM and would identify resource constraints.

1.2 Background

Typically, areas of crisis seem to occur over regions with outdated map coverage. Therefore, a quick-response product to supplement outdated maps with recent image information could be of great use to the Army. At the onset of this project, Landsat Thematic Mapper imagery seemed to offer sufficient image quality in terms of spectral and spatial resolution, as well as geometric integrity. The 16-day revisit cycle of the satellite also offered good periodic coverage. In response to requests made by U.S. Army Deputy Chief of Staff Intelligence (DAMI-ISP), image map and portfolio characteristics were developed to demonstrate the utility of such a quick response product.

1.3 Scope

Under this effort, 1:50,000-scale image maps for two geographic regions in Central America were produced in a true color mode using Landsat TM bands 1,2,3. These image maps are in the standard Universal Transverse Mercator (UTM) projection, contain imbedded 1,000-meter grid lines with labeled UTM coordinates, and can easily be used in conjunction with conventional military maps of the same scale. Annotation that gives the title of the standard Defense Mapping Agency map of the area, the Landsat TM band combinations, as well as a bar scale and compass were also imbedded into the product.

In addition, a portfolio of 1:50,000 scale registered images using other Landsat band combinations was also provided. These combinations included the Band 5-4-3 Red/Green/Blue (RGB) false color product as well as a Modified TM Tassel Cap combination.[1]

[1] The Modified Tassel Cap is a GREENESS-BRIGHTNESS-YELLOWNESS transformation based on scene-derived coefficients that are computed using a Gram Schmidt Orthogonalization Procedure. Journal Reference: Jackson, Ray. "Spectral indices in N-Space." *Remote Sensing of Environment*; Vol. 13, 1983: pp 409-42.

2.0 IMAGE PROCESSING ENVIRONMENT

The preliminary processing for both the image maps and the portfolio was done at ETL using the Space Research Test Facility, Multiband Image Processing System, (SRTF/MBIPS). The subsequent image map processing was done using this system whereas the image portfolio processing was done using a Personal Computer version of the Earth Resources Laboratory Applications Software (PC-ELAS).

The ETL SRTF/MBIPS hardware includes a Vax 11/785 computer with 24 MB memory, a Gould IP8500 image processor, a Calcomp table digitizer, eight 200 MB removable disk drives, two 6250 BPI tape drives, a 1600 BPI tape drive, a Calcomp plotter, and a number of Macintosh II microcomputers connected to the Vax 11/785 through an Ethernet. The software used was predominantly the NASA/USGS-developed Land Analysis System (LAS), although Macintosh graphics software was used to produce much of the Image Map annotation. As will be discussed below, the necessary software functions to produce Landsat-derived image maps (in approximate order of their use) include multiband data tape input, multiband image grouping, table-to-map coordinate conversion, image-to-map registration, bilinear and/or cubic convolution resampling of multiband image data, spatial image enhancements, distributional and/or cumulative image histograms, histogram-based radiometric mapping, multiband image cut and paste operations, image grid generation, as well as text and graphic annotation. The LAS software package contains all these necessary functions.

The ETL PC-ELAS system runs on a Compaq 386/20 microcomputer with a 80387 math co-processor under MS-DOS. Other hardware components include a NUMBER NINE image processing board with a 512 by 512 high resolution monitor, a 60 MB Hard Drive, a 1.2 MB High Density Floppy Drive, a 21 MB Bernoulli Drive, and a 800 MB WORM Drive. Note that ELAS is software developed by NASA/ERL and should not be confused with LAS.

The PC-ELAS had most of the capabilities needed to produce the portfolio products, and probably could have produced the image maps, provided it had additional storage and memory capacity. The major limitation of the system is its difficulty in handling the large scenes often needed to generate a search image that covers the geographic region of interest -- search images for the portfolio products were generated by LAS and passed on to PC-ELAS. Otherwise, all the subsequent processing steps for the portfolio, including image-to-map registration, the Modified Tassel Cap transformation, and various image enhancement techniques were performed on PC-ELAS.

A version of PC-ELAS used by the Waterways Experiment Station (WES) operates under UNIX, which utilizes a FAIRCHILD CLIPPER board that runs at accelerated processing rates and surpasses the performance of smaller minicomputers such as VAX 11/750.

3.0 METHODOLOGY

Two geographic areas were selected from a number of candidate target areas. Based on the coverage provided by the Landsat TM tapes given for the project and the features within the available maps, these regions were defined as the areas covered by the JUTICULPA and SAN FRANCISCO DE BECERRA 1:50,000-scale DMA map sheets. Most of the other candidate areas either contained insufficient reference features or were not located within the Landsat TM coverage that was provided.

The fact that JUTICULPA and SAN FRANCISCO DE BECERRA are adjacent map sheets simplified the processing considerably. Only one search image needed to be generated, and most of the subsequent processing steps, such as registration, image enhancement, and grid generation, only had to be performed once. The annotation as well as the final cutting and fitting to map sheets were done separately for each area. Although the location of the two areas with respect to each other simplified the processing, the location of these areas within the Landsat TM scene complicated the preliminary processing.

The major digital tasks for producing image maps are Preliminary Processing, Image-to-Map Registration, Image Enhancement, and Final Digital Preparation. These tasks are discussed below with reference to the LAS software that was used to support them. These tasks were applied to create a true color image map using bands 1, 2, and 3. Other band combinations could have easily been added to produce false color image maps utilizing the infrared bands.

3.1 Preliminary Processing

The basic objective of the Preliminary Processing task is to produce a multispectral **search image** upon which the subsequent tasks of image-to-map registration, and image enhancements are based. This task involves loading the Landsat TM imagery onto the system, locating the areas of interest, consolidating the necessary image data, and creating the search image. Figure 1 shows the consolidation of data into a multiband search image.

The preliminary processing can be trivial if the region of interest is easily identified on the image and is located in a favorable position with respect to the Landsat TM quadrant and scene boundaries. In general, however, one or both situations will occur. In our case, the selected region of interest was very hard to locate because of small reference features (predominant features were a few small towns and a number of narrow roads). This region was also located along the border of two Landsat quadrants (Q1 and Q2). Of course, the situation could have been worse if the region was situated at the corners of four quadrants or situated between two scenes rather than two quadrants. Even worse, the region could be located at the corners of four Landsat scenes. As will be discussed, some of this difficulty can be resolved with special Landsat data input programs, but these potential situations impact on the storage requirements of the processing system.

Landsat TM imagery was provided to ETL as numerous quarter scenes in the TIPS standard Band Interleaved by Line (BIL) formatted tapes. The data were imported into the LAS system using a generalized multispectral tape-to-disk transfer routine **I1RANSFER**. This routine requires that the user specify the size of the image, the

number of bands, the number of header records to skip, and choose between BIL or Band Sequential (BSQ) tape format.

Another utility which can only be used to read TIPS standard BSQ formatted tapes is the program **CCTTIPSP**. However, because the TM data in this project was supplied in BIL, this more convenient program could not be used. Using the routine would have simplified the subsequent mosaicing of quarter scenes that was needed to generate the search image. The utility reads the user-requested quarter scenes into the system and mosaics them together. For example, the following mosaicing combinations are allowed: Q1&Q2, Q1&Q3, Q2&Q4, Q3&Q4, and Q1-Q4 (full scene). Whereas a program to combine Q1&Q3 and Q2&Q4 is trivial to code, one that performs the other three combinations is not. Because such a program was not available, a trick was done to accomplish the task using the program **CONCAT** (discussed later in this section).

An attempt was made to compute the approximate location of the areas of interest, based on the full-scene corner coordinates of the Landsat TM data and the map sheet coordinates. However, the projection system of the image Space Oblique Mercator (SOM) and the projection system of the map (UTM) are different and this disallowed a straightforward calculation. The necessary software to compute an accurate estimate requires (1) a transformation from map corner coordinates to SOM corner coordinates, (2) a transformation from SOM coordinates to full-scene (line/pixel) image coordinates, (3) a transformation from full-scene image coordinates to quadrant-based image coordinates. These transformations were theoretically available under LAS, but because some of the necessary header information residing on the tape could not be extracted, and the software had not been tested under ETL's version of LAS, the decision was made to locate the areas of interest visually, rather than to delay the project.

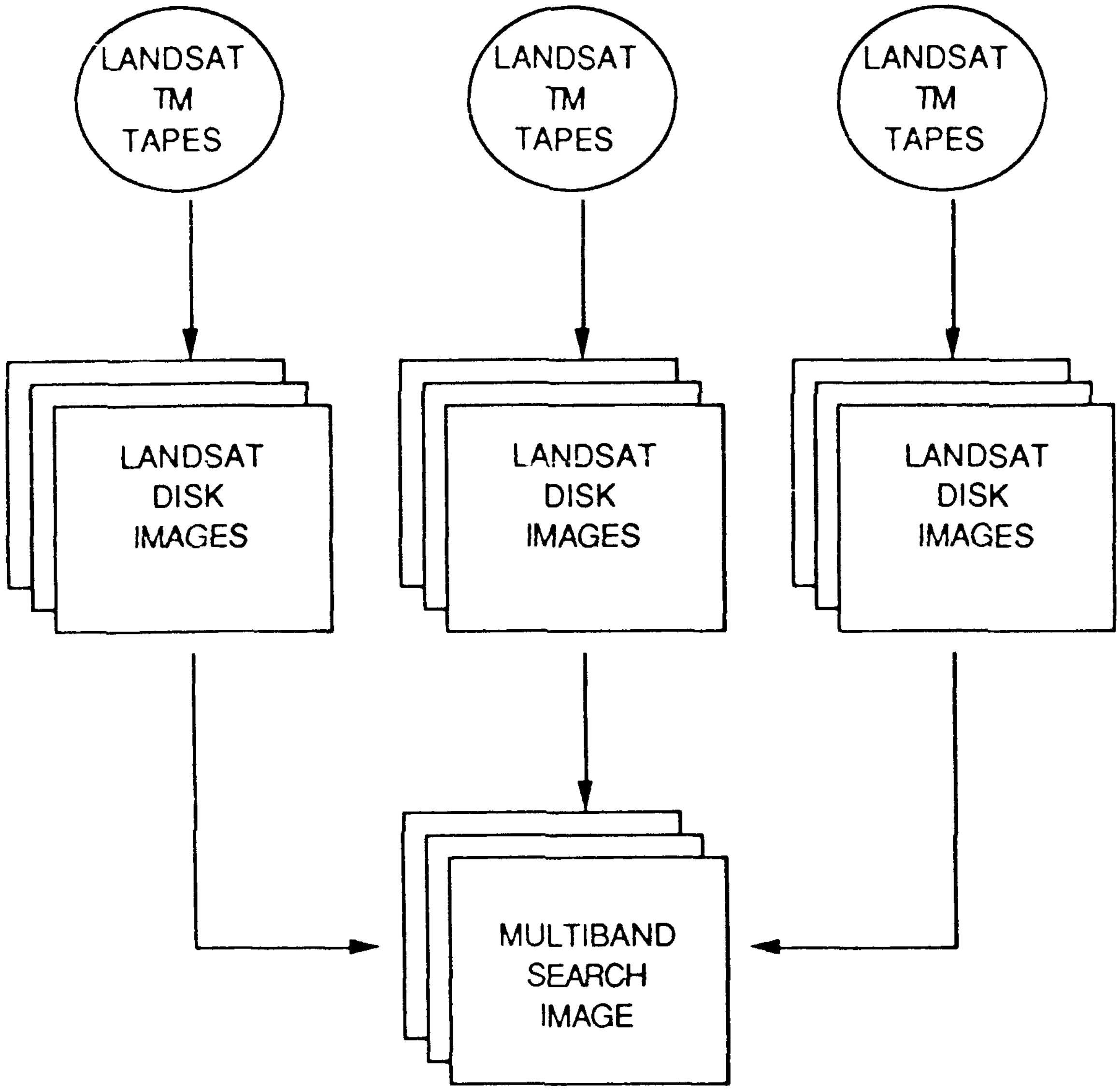

Figure 1: Consolidation of Digital Data into Multispectral Search Image

Searching the Landsat TM scenes visually for the two areas was not an easy task. One problem was that full resolution 3-band color combinations could be viewed on LAS only as 512 by 512 sized images. Because of the small reference features and the need for color contrast in locating these features, reduced resolution and/or single band viewing was not advisable; therefore, it was necessary to display and view each 512 by 512 piece of 3-band imagery separately.

The search process took about 2 to 3 hours of manual photo-interpretation effort. Misleading features in the imagery often led the analysts astray. One big problem was the difference in scales between image and map features. Another problem was working in unknown areas with few landmarks. This frustrating process made a lasting impression on the analysts.

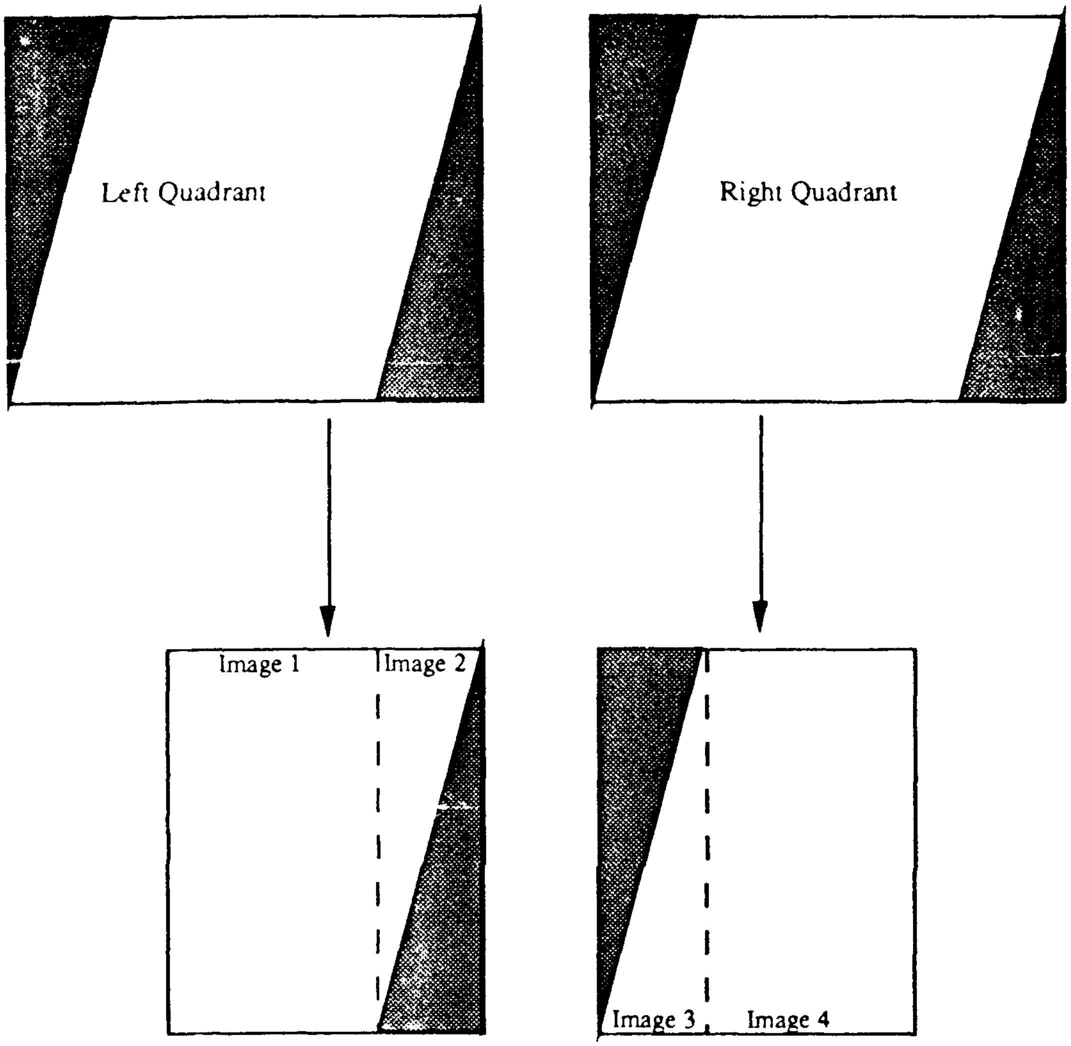

Figure 2. Combining Scenes to Obtain Regions of Interest.

The regions of interest were located and found to span two quadrants. Concatenating these two quadrants was not trivial because as can be seen in Figure 2, the SOM projected quadrants are not rectangular, but are diagonal with zero fills to the edge. The regions of interest within the two quadrant images were extracted and split into four images as shown in Figure 2 -- a left edge scene, a left (bottom-empty) diagonal scene, a right (top-empty) diagonal scene, and a right edge scene. The left and right diagonal-filled images were combined through a logical "OR" image operation using the LAS program **ORPIC**.

Finally, a search image was created by concatenating three multispectral (6 bands) images -- the left edge, the middle logically combined image, and the right edge using the program **CONCAT**. The resulting image was 2048 lines by 2048 pixels (columns) consisting of Landsat TM bands 1,2,3,4,5, and 7. The thermal TM band 6 was not extracted because of its poor spatial resolution (120 meter pixels) compared to the other bands (30 meter pixels).

Note: Storage requirements for this task can be significant. See APPENDIX A - Storage Requirements.

3.2 Image to Map Registration

The objective of the image-to-map registration step was to generate a geo-coded reference image in a UTM projection (see Figure 3). The reference image would have the property that image lines correspond to constant UTM "Northings", and image columns have constant UTM "Eastings", with each pixel resampled to have a ground size suitable for displaying at 1:50,000 scale. After certain considerations (discussed below), the resampled pixel size was chosen to be 15 meters. The size and coverage of the reference image was defined to be sufficiently large enough to cover both of the contiguous regions in JUTICULPA and SAN FRANCISCO DE BECERRA, as well as allow some additional "scratch" space along the borders to allow for the residue from any subsequent image enhancements that were anticipated.

One effect produced by the above approach to align the image lines with UTM "Northings" is that the resulting image maps were cut according to UTM gridlines instead of geographic latitude and longitude lines. Therefore, the corner coordinates of the image map will not correspond exactly to the standard geographic corner coordinates generally found on DMA map sheets. The primary reason for cutting the image map in this way was to avoid a jagged stair-stepping effect that would otherwise have been produced when the gridlines were engraved into the image. The coverage of the resulting image maps was made slightly larger than the conventional maps so that all the standard corners of these maps would be included.

3.2.1 Extracting Image and Map Coordinates

Nine ground control points (GCPs), also known as tiepoints, were used to develop the image-to-map transformation parameters for producing the reference image. These points were scattered as evenly as possible throughout the JUTICULPA and SAN FRANCISCO DE BECERRA areas; however, the lack of identifiable points in the region made it impossible to define a well-distributed GCP pattern. Each tiepoint (GCP) had to be a well-defined spot on the image and the map (such as a road intersection), where no ambiguity existed between the image and map. Ambiguity occurs when there are new/changed image features surrounding the tiepoint, such as additional road intersections, or when there is too much detail surrounding the tiepoint as occurs in urban/town areas.

The image coordinates for each tiepoint were extracted as line and pixel values and stored in a tiepoint selection file using a LAS tiepoint data input program **COORDEDT**. Typically, each point was magnified 4 to 8 times its original scale and was displayed in a false-color band combination. In retrospect, some image enhancements (such as those discussed later) to emphasize the edges and spectral contrast of candidate tiepoints might have aided this process. However, this would need to be done with caution because it could also shift the position of edges slightly and reduce the precision of the point locations.

The map coordinates for each tiepoint were extracted by first obtaining table coordinates generated by a digitizing table and then storing them as a tiepoint selection file. In order to obtain the UTM coordinates, a table-to-map transformation grid was computed for each of the two map sheets using a polynomial fitting program **TIEFIT**. The inputs to this program for the first transformation grid were merged tiepoint selection files corresponding to table and map sheet coordinate pairs of four UTM grid intersections located near the edges of the first map sheet. The inputs for

the second grid were the merged tiepoint files for the second map sheet. The merging of tiepoint selection files was done by the combined action of the programs TIEMERGE and NULLCORR.

The table coordinates for the tiepoints within the first map sheet, along with the first table-to-map transformation grid, were input into a coordinate transformation program **TRANCOORD** to generate the corresponding UTM coordinates. The procedure was repeated using the table coordinates for the tiepoints within the second map sheet, along with the second grid, to obtain the remaining UTM coordinates.

3.2.2 Computing UTM Reference Image Coordinates

The image-to-map registration process requires that a discrete[2] UTM reference image space be computed to define the output space into which the pixels in the multispectral search image will be mapped. This reference image space is not an image file. It is an abstract space that is used to determine the geographic coverage and the ground spot size of the geocoded image pixels, as well as to supply discrete UTM tiepoint coordinates that are referenced to a locally defined origin. The discrete UTM coordinates of the tiepoints are subsequently used with the image coordinates during the registration process to define an image-to-map transformation, as is discussed next in **Registration Process**

The UTM reference image space was generated using **TRANCOORD**. Inputs to this program were the UTM coordinates of the tiepoints being used to define the image-to-map transformation, a grid origin that defined the upper left corner of the geographic area, and the grid cell size that determined the output spot size of the geocoded reference image pixels. The output was a tiepoint selection file that contained discrete UTM coordinates referenced to the locally defined origin.

A 15-meter UTM grid cell size was selected. One reason for choosing this size was that it would allow embedding a grid without loss of image content (Landsat TM original resolution being 30 meters). Also, since USGS had been successfuly using a 25 meter grid for producing 1:100,000-scale image maps, a 15 meter grid seemed reasonable for 1:50,000.

Table 2 (see Section 4.0) should help clarify this discussion of the UTM Reference Image. The table lists, along with search image coordinates, the original UTM coordinates and the discrete UTM coordinates for the limiting edges of the region of interest and the locations of the nine tiepoints.

3.2.3 Registration Process

The steps outlined above produced two tiepoint selection files: one for the image and the other for the UTM reference grid. During the registration process, the files were merged using **TIEMERGE** and **NULLCORR**, and then input to the **TIEFIT** program, which generated an image-to-map transformation grid.

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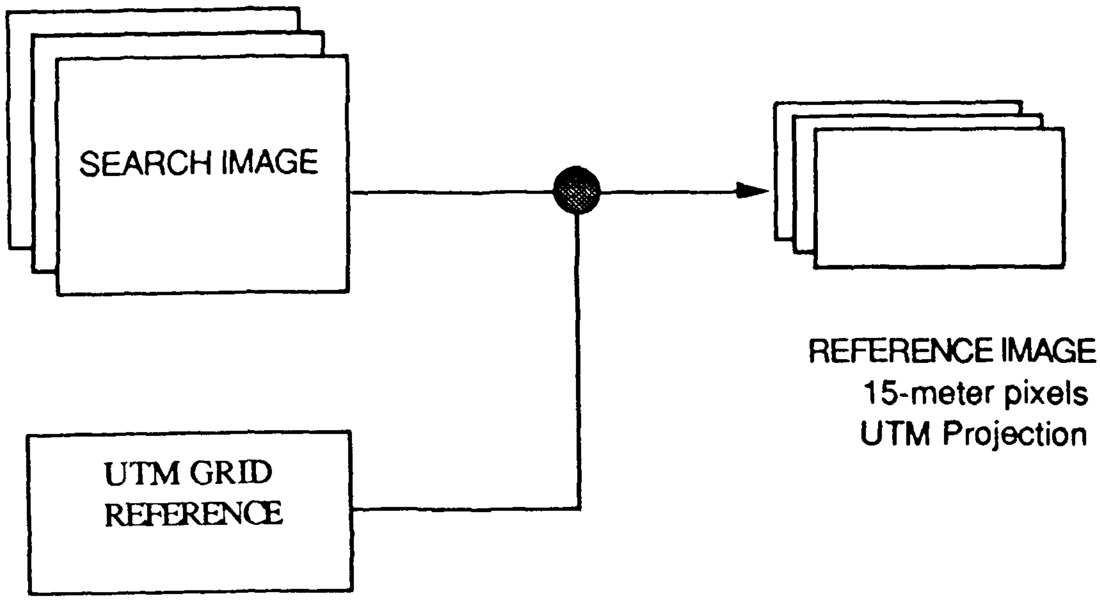
2 The term "discrete" is used in contrast to "continuous". The UTM coordinate system is necessarily continuous; however, a discrete coordinate system must be used in the image-to-map registration process.



Linear transformation provided best fit

$$FX = A(0) + A(1)X + A(2)Y$$
$$FY = B(0) + B(1)X + B(2)Y$$

Figure 3. Image to Map Registration Process

TIEFIT can generate up to a 4th degree polynomial mapping for doing the registration. Generally, the simplest polynomial that generates sufficient accuracy should be used. Polynomial functions higher than 1st degree can become very unstable outside the region defined by the tiepoints. Accuracy is usually measured in terms of residual errors between predicted and actual values of the tiepoints.

For this project, a first-degree polynomial mapping was found to be sufficient. Other investigators have drawn similar conclusions for local mappings between Landsat TM's SOM projection and the UTM map projection.[3] The residual errors for this study are given in the **RESULTS** section.

The program **GEOM** was used for producing the UTM-registered multispectral reference image. For each point in the UTM reference grid, GEOM computes the corresponding search image coordinates, using the image-to-map transformation grid. Because the computed locations are not integer values, the pixel gray shades for these locations are calculated using one of three resampling methods: nearest

[3] Welsh, R. *Jordan*, T.R. and Ehlers M. "*Comparative Evaluations of the Geodetic Accuracy and* Cartographic Potential of Landsat-4 and Landsat-5 Thematic Mapper Image Data", *Photogrammetric Engineering and Remote Sensing*, Vol. 51, No. 9, Sept 1985: pp 1249-1262.

neighbor, bilinear interpolation, or cubic convolution. The nearest neighbor method often produces resampled images with a blocky appearance; whereas, cubic convolution is very compute intensive and often produces a smoothed effect. For this project, bilinear resampling was selected because it produces sufficient smoothing with less computation than the cubic convolution.

An alternate program **REGISTER** combines the functions of TIEMERGE, NULLCORR, TIEFIT, and GEOM. REGISTER is generally more convenient to use, because it eliminates the need for calling multiple modules and saving a number of intermediate files. However, the use of the TIEMERGE, NULLCORR, TIEFIT, and GEOM sequence offers more control over individual processes, and the intermediate files are useful if it becomes necessary to retrace any steps.

3.3 Image Enhancements

An edge enhancement to the multispectral reference image was made by applying a boxcar filter to each of the three bands. The effects of using a 3 by 3, 5 by 5, and a 7 by 7 boxcar filter were observed. Of the three filters, the 7 by 7 boxcar produced the best edge enhancement, and it was selected for enhancing the multispectral reference image. This filter is defined as follows:

$$Y_{ij} = X_{ij} + C\,(X_{ij} - \bar{X}_{ij})$$

where $\bar{X}_{ij}$ = Mean Value of all Pixels inside of Kernal Centered at X_{ij}
X_{ij} = Input Pixel Value
C = Constant to Control Amount of Enhancement (0-1)
Y_{ij} = Output Pixel Value

Note that a value of C=1 yields the maximum contrast enhancement.

The LAS program **EDIPSEDGE** was used to apply this enhancement with a value of C = 1.

The radiometric enhancements were then applied to the edge-enhanced multispectral reference image according to the guidelines of a USGS Reference manual for producing image maps.[4] According to this method, either the image's probability distribution or cumulative distribution histogram can be used to develop a multiple-point linear contrast stretch of the pixel values. For the probability distribution method, the percent of pixels per histogram bin determines the breakpoint values for the contrast stretch. For the cumulative histogram method, the breakpoint values are determined by the cumulative percentage of the total number of pixels. These methods are shown below in Table 1.

[4] *Procedure Manual for Preparation of Satellite Image Maps*, Open File Report 86-19, Department of the Interior, U. S. Geological Survey, National Mapping Division.

Table 1. Estimated Breakpoint Values for Multiple-Point Linear Contrast Stretch.

Method 1 Percent Pixels/Bin	Method 2 Cumulative Percentage	Contrast Stretch Mapped Pixel Values
0.0%	0.0%	0
0.1%	0.5%	10
0.8%	5.0%	25
mode	50.0%	110
1.0%	95.0%	205
0.15%	99.5%	240
0.0%	100.0%	255

Both methods were tried on the reference image using the program **PIXCOUNT** for extracting histograms and **MAP** to apply the multiple-point stretch. Obvious clouds were masked out of the histogramming. This would also have been true of any obvious water bodies if they had been present in the scene. The probability histogram method seemed to produce the best looking true-color image on the display, and was therefore retained for subsequent processing. However, as will be discussed later, this automatic assignment did not produce an optimal hardcopy appearance, and some subjective adjustments were made to slightly modify the stretch parameters to obtain a more visually pleasing image. The final radiometric mappings are reported in the **RESULTS** section.

3.4 Final Digital Production Steps

Once the enhanced multispectral (true color) image was produced, the final digital production steps were applied. These steps included engraving a map grid into the reference image; extracting the two map scenes from the engraved reference image and positioning these scenes in a "white" template image; and annotating the white template with useful map reference information.

3.4.1 Grid Generation

The goal of the grid generation task was to engrave a rectangular grid pattern on the image that corresponds to a 1,000 meter grid pattern on the ground. The engraving process actually replaces image pixels with the grid; however, since the reference image was generated with 15-meter pixels and the original Landsat TM imagery had 30-meter pixels, no image information was lost. This was one of the motivations for choosing the 15 grid cell for the resampling process.

The program **GRID** was used to generate the desired grid pattern. This pattern could have been burned directly into the multispectral reference image or into a template image (with a white background) that would be subsequently merged with the reference image. The second method of using a template image was chosen because it kept the grid generation process isolated from the other processes. Therefore, if it became necessary to retrace to a prior step, such as additional radiometric enhancement, the same gridded template could be used.

GRID operates in image space rather than in map (ground) space, generating a gridline for every Nth pixel. Thus, it is necessary for the user of GRID to make a correspondence between the desired grid spacing on the ground and the defined pixel spacing. An accurate grid can only be produced for ground spacings that are an integer multiple of the pixel spacing.

For this project, the desired grid spacing was 1000 meters and the pixel spacing was 15 meters. Because 1000 meters divided by 15 meters does not yield an integer N value, an accurate grid could not be produced in one step. Three 3,000 meter grids (N=200) were generated -- the 2nd grid was positioned 67 lines and pixels (1,000 meters) from the first, and the 3rd grid was displaced 133 lines and pixels (2000 meters) from the first. The combined grids resulted in an accurate 1000-meter grid.

The resulting 1000-meter gridded template image was then merged with the enhanced multispectral reference image using the LAS program **OVERLAY**.

3.4.2 Extracting and Positioning of the Final Scene

The longitude/latitude corner coordinates of each map sheet were converted to UTM coordinates in order to obtain the boundaries of each desired image map. This was done using the LAT/LON-to-UTM coordinate conversion option within the **TRANCOORD** program. The boundaries were chosen to enclose the entire area of each map sheet. Since the image maps were to be cut along UTM lines and the reference maps were cut along latitude and longitude lines, this process resulted in the image maps covering a slightly larger geographic area than the reference map.

The size of the "white" template image was derived according to photo lab size constraints that allow a maximum 20 by 24 inches for paper products. To fill a 20- by 24-inch area with 15-meter ground pixels reproduced at 1:50,000 scale, the template image must have a size of 1692 lines and 2030 pixels.

The JUTICULPA and SAN FRANCISCO DE BECERRA scenes were extracted from the gridded and enhanced multispectral reference image, and placed into the "white" image using the program **CONCAT**.

3.4.3 Annotation

Most of the text and graphic annotation for the image maps were created using Apple Macintosh graphics software. The resulting annotation were 1-bit graphic files that were converted to 8-bit images using a government-developed Macintosh program **IMAGE 1.01** and transferred to the VAX 11/785 via an Ethernet connection. One example is the Magnetic Compass shown below in Figure 4. The Apple program allowed lines and text to be drawn and rotated at any specified angle. Scribing the UTM coordinates along the sides of the imagery was done using LAS and was the most tedious and time-consuming annotation task.

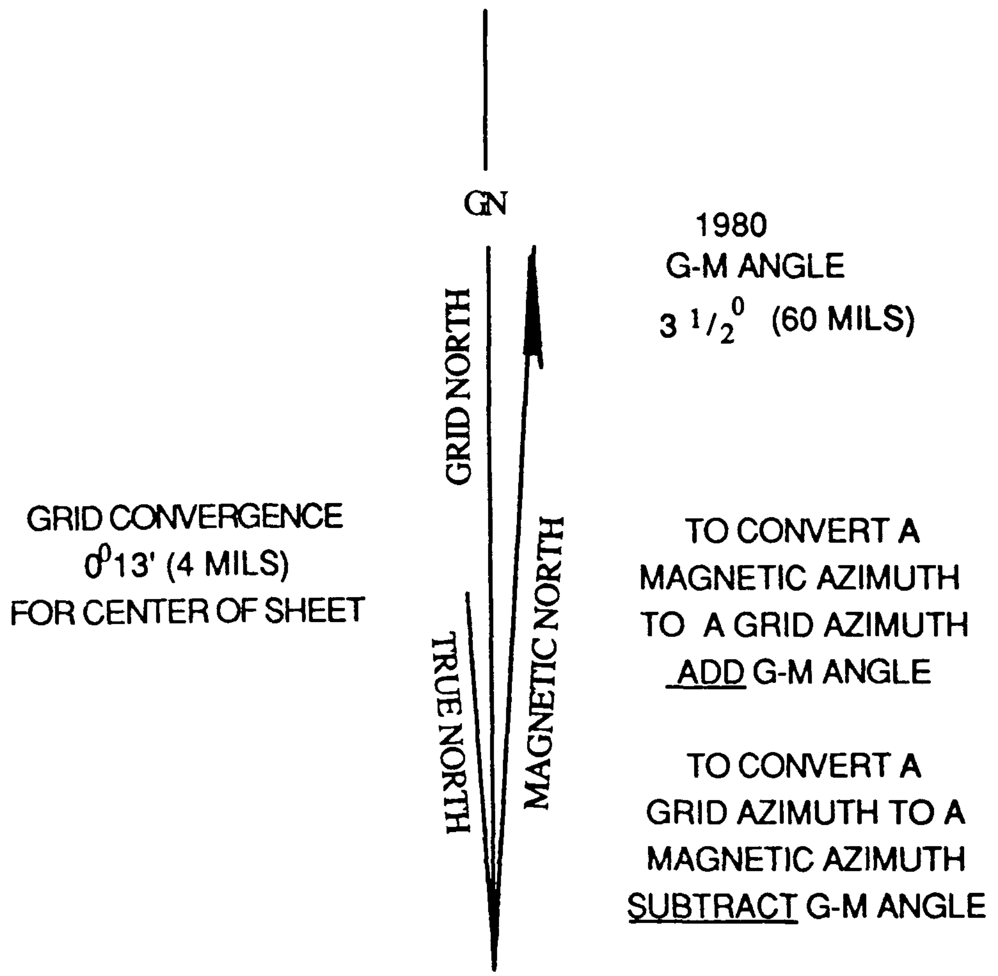


Figure 4. Magnetic Compass Generated by Graphics Software.

3.5 Hardcopy Production

The final task was to produce a hardcopy version of the digital image map. Because ETL had no suitable hardcopy device to support the project, hardcopy services were provided by WES and DIA.

Three methods of hardcopy support were provided by WES. The first method used a CALCOMP 5835 color plotter with a resolution of 400 dots/inch that was used to produce color plots of the image maps at 1:50,000 scale directly from the digital tapes. The second method used another color plotter to produce one version of the image portfolio at 1:50,000 scale. The third method used a matrix camera to produce another version of the image portfolio at 1:50,000 scale.

A very high quality photographic method of hardcopy support was provided by DIA, using a FIRE 240 film recorder with a 12.5 micron spot size that could handle up to 16,000 pixels by 16,000 lines for producing three color separates on 9 inch black & white roll film. The 3 separates were then registered and transformed into color using a Vericolor III, and subsequently enlarged to a 20- by 24-inch color print.

Upon submitting the digital image products to WES and DIA, the hard copy draft products were produced. It was immediately recognized that some further radiometric adjustments would have to be made. In both cases, the products had a purple overtone to them and the green vegetation seemed suppressed. Some attempt was made by DIA to enhance the image maps with their digital interface system to the Fire 240; however, a second iteration at ETL was required. This required stepping back to the image enhancement phase and repeating the remaining tasks. Acceptable results were obtained from using the final radiometric mappings listed in Table 4 of Section 4.

4.0 RESULTS

The image registration results are given in Table 2 and Table 3. In Table 2, the original UTM coordinates and the discrete UTM coordinates are listed for the limiting edges of the region of interest and the locations of the nine tiepoints. This table also lists the corresponding image coordinates for the tiepoints within the search image. In Table 3, the registration results are listed by giving the residuals for each tiepoint.

In order to obtain acceptable registration results, the tiepoint T06 had to be eliminated from the tiefitting computations. The acceptable polynomial mapping function was a first-degree linear transformation:

$$X' = A_0 + A_1 X + A_2 Y \qquad \text{where} \quad A_0 = 212.9034 \qquad B_0 = 568.3114$$

$$Y' = B_0 + B_1 X + B_2 Y \qquad A_1 = 0.5224033 \qquad B_1 = -0.7547104$$

$$A_2 = 0.7747684 \qquad B_2 = 0.5225393$$

The results in Table 3 show that this transformation generates a low residual error rate for the tiepoints. The average squared residual for x and y were both within a pixel and the maximum residual error was -1.6 pixels. Therefore, the geometric accuracy of the resulting image maps should be quite good, at least in the areas of flat topography with approximately the same elevation as the tiepoints.

Based on the corner limits of the map sheets and the pixel size, the size of the JUTICULPA scene was computed as 1230 lines by 1806 pixels, and the size of the SAN FRANCISCO DE BECERRA scene was computed as 1236 lines by 1806 pixels.

The original radiometric mappings were based on the procedures outlined in Section 3.3. As mentioned previously, the first iteration resulted in a hardcopy product with an undesirable purplish overtone. In order to compensate for this effect, subjective refinements were made that lowered the bias in the blue band and raised the bias in the green band. The final radiometric mappings applied to the image data are given in Table 4.

Table 2. UTM and Image Coordinates of Boundaries and Tiepoints.

Point	Original UTM Coordinates		Discrete UTM Coordinates		Search Image Coordinates	
	Easting	Northing	Pixel	Line	Pixel	Line
North West Edge	579250	1640750	1	1	—	—
T01	584304	1619296	1430	337	1290	499
T04	588409	1624937	1054	610	1074	614
T06	583472	1620716	1336	281	1238	462
T08	584017	1608558	2146	318	1666	545
T09	585992	1608703	2136	449	1651	613
T10	589442	1613579	1811	679	1463	709
T11	592022	1627327	895	851	970	728
T12	597649	1629446	754	1227	871	911
T13	604791	1631748	600	1703	753	1149
SouthEast Edge	608750	1602250	1967	2567	—	—

Table 3. Residual Errors

Tiepoint Name	Y- RESIDUAL	X-RESIDUAL
T01	-0.26	-0.75
T04	0.91	0.44
T08	0.23	-0.19
T09	0.24	-0.23
T10	-0.54	0.79
T11	-1.6	0.94
T12	1.5	-1.1
T13	-0.4	.082

The average squared x-residual was .4421 pixels.
The average squared y-residual was .7888 pixels.

Table 4. Radiometric Mappings

BLUE (B1)		GREEN (B2)		RED (B3)	
FROM	TO	FROM	TO	FROM	TO
16	5	0	5	0	5
57	10	17	10	14	10
60	15	19	25	16	25
73	80	31	110	28	110
84	185	37	205	42	205
90	235	42	240	53	240
124	250	67	250	94	250
255	250	255	250	255	250

A subjective "visual analysis" of the hardcopy products was conducted by the project team members to assess its overall quality. After the final radiometric mappings were applied, the visual quality was determined to be very good. The color balance and contrast portrayed a pleasing true color image. A good amount of edge detail delineated many loose-surface roads of sub-pixel size. Some significant man-induced changes, such as new roads and expanded cultural areas, could be noticed on the multispectral image maps that were not present in the older DMA reference maps.

Further assessment is currently being planned, whereby the multispectral image maps will be provided to Army tactical planning and topographic teams. These teams will evaluate the image maps for supporting their particular missions.

5.0 CONCLUSION

The project members were quite pleased with the resulting image map products. These products appeared to offer very good utility to Army users. Numerous changes of military interest that did not appear on the reference map were easily noticed on the new products. The geometric registration between the image maps and the corresponding reference maps were also very good (although, it should be noted that the area was relatively flat). Because of the good geometric corresponence, any changes of interest could be easily related to the map. Feedback from Army user is the ultimate test, and is being awaited.

This effort was not intended to identify ETL as a standard production facility for image maps. Upon completion of this work, however, ETL now believes it could produce the digital form of such prototype image maps in crisis situations within two weeks upon receipt of the image data. But it should be emphasized that ETL's system, currently capable of producing the products demonstrated in this effort, is not optimized for such processing. The system is basically a general purpose Multiband Research & Development facility.

The general multispectral/multiband capabilities, which ETL's system provides, offer the Army additional advantages. For example, another ongoing ETL effort, "Multispectral Change Detection", is showing that this system can perform reliable change detection on multidate multispectral imagery. Combining the image map capability, currently demonstrated, with the change detection capability to provide change detection maps would be a trivial task. Another relevent effort is ETL's Multispectral Terrain Analysis project. This effort is developing reliable methods for using Landsat TM to facilitate the production of Tactical Terrain Analysis Data Base (TTADB) overlays, as well as to facilitate the update of existing TTADB overlays.

Therefore, image maps generated from Landsat TM are the first of many digital and hardcopy products that can benefit the Army. Once the image data is geocoded into a map reference system, as has been currently demonstrated, any of a number of successful multispectral processing techniques (such as change detection or map update) can be applied to produce Army value-added products.

The major limitation identified by this effort has been the lack of a quality hardcopy device. At a minimum, a formal memorandum of agreement should be established with a capable government agency for hardcopy production of digital data. The disadvantage of this approach is not only the slow turn around time in producing the final product, but the inability of the analyst performing the digital processing to optimize the visual appearance of the hardcopy output, which ultimately requires some subjective refinements. Ideally, ETL should acquire its own hardcopy film writer device.

APPENDIX A - Storage Requirements

The mass storage requirements for generating image maps can be quite significant. This section discusses the storage allocation scenarios that could arise during the preliminary processing steps, as well as the actual storage requirements needed to generate the two image maps completed under this project. The discussion should be sufficient to allow project managers to predict storage requirements under other image map production scenarios.

Standard Landsat TM Computer Compatible Tapes (CCTs) are supplied as quarter scenes and require significant disk storage capacity due to the large amount of pixel data. The image sizes for CCT-P (geometrically corrected) data are as follows:

Quadrants 1 & 3:	4220 pixels * 2983 lines * 7 bands
Quadrants 2 & 4:	4220 pixels * 2982 lines * 7 bands

The number of bands to be stored depends on the type of image map being produced. In order to produce a color image map, one must save at least three bands. Additional bands have to be stored if more than one color combination is produced. For example, four bands would need to be stored if both the standard true color (B1, B2, B3) and the standard false color (B2, B3, B4) image maps were being produced. Four bands would also be needed if the site selection and control point selection were performed using a false color combination (as was done in this project) and a true color image map was being produced.

The minimum storage requirement for Quadrants 1 or 3 is therefore 37.8 megabytes. However, computer systems do not usually store data in such a compact format. They usually store data in 512 byte blocks, which effectively increase this requirement. Therefore, a more practical storage requirement for writing a 3-band Landsat TM quadrant (Q1 or Q3) to disk is 41.3 megabytes (9 * 512 * 2983 * 3).

Often times target areas will be located between quadrant or scene boundaries thereby increasing storage requirements beyond that required for a single quadrant. System resources should be sufficient to allow for any potential variations.

If a system has the software to merge the quarter scenes into half scenes or full scenes, the final merged size for CCT-P data will be as follows:

Half TM Scene:	6967 pixels * 2983 lines * N bands
Full TM Scene:	6967 pixels * 5964 lines * N bands

The processing of a full scene would therefore require a practical storage capability of 128.3 megabytes (for N = 3 bands). Note that the discrepancies between the half/full scene size and the combined quarter scene sizes are due to left and right zero-fill pixels within the full and quarter scenes.

Once the appropriate scenes are loaded onto the system, a search image must be created and stored, followed by numerous other image files. Table 5 lists the sizes and storage requirements for all the intermediate and final files needed to produce the two image maps for this project.